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Concussion and Mild Traumatic Brain Injury: An Annotated Bibliography

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14. ABSTRACT

Concussion and post-concussive symptoms are of special concern to the military given the large number of Soldiers returning from combat who have sustained a head injury. This type of injury presents a unique challenge to the military medical community. The objective of this report is to provide an inventory of the fields and key references pertaining to concussion, deficits following concussion, and its impact on the Soldiers. At present, concussion is a key topic area for U.S. Army research and progress is begin made in understanding the injury. However, much work remains to be done in this area and concussion will remain an important topic in the future.

15. SUBJECT TERMS

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Introduction

Concussion and post-concussive symptoms are of special concern to the military given the large number of Soldiers returning from combat who have sustained a head injury. In fact, traumatic brain injury (TBI) is so prevalent that it has been suggested to be the signature injury of the wars in Afghanistan and Iraq (Crooks, Zumsteg, & Bell, 2007). One causal factor of this trend is the use of improvised explosive devices (IEDs) by insurgents, the blast impact from which may result in a concussion. This type of invisible injury presents a unique challenge to the military medical community. The objective of this report is to provide an inventory of the key references pertaining to concussion, deficits following concussion, and its impact on the Soldier. At present, concussion is a key topic area for U.S. Army research, and progress is being made in understanding the injury. However, much work remains to be done in this area and concussion will remain an important topic in the future.

Background

A typical definition of a concussion is any head injury that results in an altered mental status (also known as a mild traumatic brain injury, or mTBI). Typical complaints following concussion include vestibular (e.g., vertigo), auditory (e.g., tinnitus), physical (e.g., headache), psychological (e.g., depression), sleep, and cognitive (e.g., attention) disturbances or deficits. Concussion can result from blunt strikes (something striking the head of the individual) or blast exposure (injuries associated with the concussive blast of an explosion).

It is estimated that a large proportion of Soldiers are returning from war with concussive injuries. In 2008, Hoge et al. surveyed 2525 U.S. Army Soldiers approximately three to four months after completing a year-long deployment in Iraq. Their findings demonstrated that almost 15 percent of the respondents reported a concussion, of which 5 percent reported a loss of consciousness, and 10 percent who reported ‘being dazed’ or ‘saw stars.’ Soldiers who sustained concussions were more likely to have physical and mental health problems. In addition, a recent report published by the RAND Corporation (Tanielian & Jaycox, 2008) documented the psychological sequelae of deployments, and estimated that 320,000 U.S. Soldiers incurred a probable traumatic brain injury while serving.

According to Shaw (2002), concussion is the most common and puzzling type of TBI. A concussion is produced by acceleration or deceleration of the head and brain, which can result in shearing and stretching of neurons. According to the National Center for Injury Prevention and Control Centers for Disease Control and Prevention (2003), concussive injury is a “silent epidemic,” given the difficulty of diagnosis. Symptoms of concussion include, but are not limited to; headaches, vertigo, confusion, sleep disturbances, balance problems, and even irritability or violent behavior. More severe cases of TBI include: 1) an extended period of unconsciousness (coma) or amnesia following the injury, or 2) a high rate (43 percent) of injury related disability one year after injury, and all of the previously described symptoms associated with concussive injuries. It should be noted that a concussion can occur with or without a loss of consciousness. The American Academy of Neurology (AAN, 1997) defines three grades of concussion, and both Grades 1 and 2 involve no loss of consciousness, while only Grade 3 involves a loss of consciousness. Blast exposure produces three potential concussion causal

mechanisms: 1) the shockwave of the blast, 2) debris striking the individual's head, and 3) the individual's head striking an object as his/her body is projected or propelled due to the blast exposure.

There is a great need for a consensus on thresholds at which no loss of function occurs and the upper limits at which the changes in function are irreversible (Zhang, Yang, & King, 2004). The most common cognition-related complaints following a concussion include impaired attention, concentration, memory, and information processing speed (National Center for Injury Prevention and Control, 2003). There are, however, several factors influencing the functional impact of a concussion including, but not limited to, impact magnitude, impact location, loss of consciousness, blast induced vs. blunt impact induced injuries, and previous history of concussion. At this time, the thresholds of these factors, which result in concussion, are unknown. Current research is investigating the independent roles and interactions of individual differences and injury characteristics on the severity of injury, development of post-concussive syndrome, and functional deficits. What follows is a collection of key references that reflect the current state of the literature on concussion (as a mild form of traumatic brain injury) and post-concussion syndrome (i.e., cognitive deficits and behavioral disorders).

Abbreviations

DTIC- Defense Technical Information Center

GCS – Glasgow Coma Scale

IED- improvised explosive device

LOC- loss of consciousness

mTBI- mild traumatic brain injury

PCS- post-concussion syndrome

PTA- post-traumatic amnesia

PTSD- post-traumatic stress disorder

SAC- Standardized Assessment of Concussion

TBI- traumatic brain injury

VA/DOD- Veterans Affairs/Department of Defense

References

American Academy of Neurology: Practice parameter: The management of concussion in sports summary statement. 1997. Report of the Quality Standards Subcommittee. Neurology, 48, 581-585.

This article serves the purpose of establishing the guidelines for neurologists to diagnose and provide treatment for concussion by providing a definition and graded classifications, along with recommendations for athletes on procedures of recovery from each graded injury. Lastly, ideas for future research are discussed.

Axelrod, B.N., Fox, D.D., Lees-Haley, P.R., Earnest, K., Dolezal-Wood, S., and Goldman, R.S. 1996. Latent structure of the post-concussion syndrome questionnaire. Psychological Assessment, 8(4), 422-427.

Evaluated the PCS Questionnaire with a large sample of medical and psychiatric patients. Results were evaluated based on 3- to 5-factor analytic models. The results suggest that the best fit for the PCS questionnaire is a 4-factor solution, utilizing scores in psychological, somatic, cognitive, and infrequent complaints as clusters.

Balaban, C.D., and Hoffer, M.E. 2009. Mild Traumatic Brain Injury: Vestibular Consequences. Retrieved from http://www.dcoe.health.mil/Content/Navigation/Documents/Balaban.pdf.

Many Soldiers experience vestibular disorders following a concussive event, suggesting that an alternate test battery sensitive to the vestibular system may be more appropriate. Here, a test battery utilizing visual processes and stability was used to diagnose mTBIs. To prevent long term suffering, the researchers suggest early intervention and countermeasures (possibly antioxidant) immediately following blast mTBIs.

Barkhoudarian, G., Hovda, D. A., and Giza, C. C. 2011. The molecular pathophysiology of concussive brain injury. Clinics in Sports Medicine, 30(1), 33-48.

Review of research concerning concussion injuries: outlines both the short and long term affects of mTBI, the mechanism of the injury, and the risks of suffering an additional concussion, especially immediately following injury. Physicians must be able to diagnose and treat concussed individuals accurately to prevent long term consequences.

Barth, J.T., Macciocchi, S.N., Giordani, B., Rimel, R., Jane, J.A., and Boll, T.J. 1983. Neuropsychological sequelae of minor head injury. Neurosurgery, 13, 529-533.

This article discusses early research concerning mTBI and the prediction of cognitive impairments. Concussed individuals were tested following the injury. Factors such as the individual's age and level of education predicted cognitive deficits. The presence of PTA and the length of time unconscious following mTBI did not impact the observed deficits.

Batchelor, J., Harvey, A.G., and Bryant, R.A. 1995. Stroop colour word test as a measure of attentional deficit following mild head injury. The Clinical Neuropsychologist, 9(2), 180-186.

To test the hypothesis that mTBI results in impairment of focused attention, researchers evaluated performance of recently injured (mTBI) individuals on the Stroop Test. When compared to matched controls, mTBI individuals performed worse on the original, modified, and interference conditions of the Stroop Test, demonstrating support for impairment in focused attention following mTBI.

Belanger, H.G., Kretzmer, T., Vanderploeg, R.D., and French, L.M. 2010. Symptom complaints following combat-related traumatic brain injury: Relationship to traumatic brain injury severity and posttraumatic stress disorder. Journal of the International Neuropsychological Society, 16, 194-199.

Previous research demonstrates that those with mTBI endorse more symptoms than those with moderate to severe TBI. Utilizing the Neurobehavioral Symptom Inventory (NSI) and the PTSD Checklist, researchers found similar results. However, when PTSD symptom severity was controlled for, patients with mTBI no longer endorsed more complaints than the moderate to severe TBI patients. This suggests emotional symptoms may play a role in the complaints of mildly injured patients.

Belanger, H.G., Kretzmer, T., Yoash-Gantz, R., Pickett, T., and Tupler, L.A. 2009. Cognitive sequelae of blast-related versus other mechanisms of brain trauma. Journal of International Neuropsychological Society, 15, 1-8.

With the increase in use of IEDs, it is important to understand neuropsychological differences between blast and blunt force induced TBI. The study found no main effects of severity or mechanism (blunt, blast) on cognitive performance. However, when looking only at visual memory, an interaction between severity and mechanism emerged such that when compared to non-blast related TBI individuals, those with mild blast-related TBI performed better, and, in contrast, those with moderate to severe blast-induced TBI performed worse.

Belanger, H.G., and Vanderploeg, R.D. 2005. The neuropsychological impact of sports-related concussion: A meta-analysis. Journal of the International Neuropsychological Society, 11, 345-357.

Utilizing a meta-analysis, the effect of a concussive injury on performance across six cognitive domains was evaluated for athletes and compared to non-sports-related concussive injuries. Overall, the sports-related injuries resulted in deficits similar to non-sports-related concussion. Although impairments existed for recent injuries, they resolved after 7 days following the injury.

Bleiberg, J., Cernich, A.N., Cameron, K., Sun, W., Peck, K., Ecklund, J., Reeves, D., Uhorchak, J., Sparling, M.B., and Warden, D.L. 2004. Duration of cognitive impairment after sports concussion. Neurosurgery, 54(5), 1073-1080.

To improve upon the defined timeline for recovery from concussion, athletes were tested with a computerized neuropsychological battery during the preseason and in the days following injury. Full recovery appeared within 3 to 7 days following the injury. This further suggests the practicality of a "1 week off following concussion" guideline for injured athletes.

Bruce, J.M. and Echemendia, R.J. 2003. Delayed-onset deficits in verbal encoding strategies among patients with mild traumatic brain injury. Neuropsychology, 17(4), 622-629.

The use of semantic clustering on the Hopkins Verbal Learning Test was measured for concussed individuals at 2 hours, 48 hours, and 1 week post-injury to evaluate verbal memory deficits following mTBI. Results demonstrated that concussed individuals used less clustering strategies than non-injured individuals at 48 hours post-injury, but minimal differences were found 2 hours post-injury. Additionally, concussed individuals used less semantic clusters at the 48-hour than the 2-hour post-injury testing time. These differences were not apparent, however, 1 week post-injury.

Bruce, J.M., and Echemendia, R.J. 2009. History of multiple self-reported concussions is not associated with reduced cognitive abilities. Neurosurgery, 64(1), 100-106.

Athletes with self-reported concussion histories were either given a computerized neuropsychological battery, a traditional neuropsychological battery, or both. The researchers found no association between self-reported concussion history and performance, and no differences associated with test format (computerized versus traditional) emerged.

Buki, A. and Povlishock, J.T. 2001. All roads lead to disconnection? – Traumatic axonal injury revisited. Acta Neurochirurgica, 148(2), 181-194.

Review paper detailing the structural damages of traumatic axonal injury (TAI) associated with mTBI in humans. Evidence has demonstrated that TAI is not evident immediately following injury, and pathogenesis following injury adds to the structural damage following mTBI.

Canadian Academy of Sport Medicine Concussion Committee. 2000. Guidelines for assessment and management of sport-related concussion. Clinical Journal Sport Medicine, 10, 209–211.

This article discusses guidelines for concussions of Canadian athletes. Concussions are defined, along with their symptoms, signs, and grades for proper diagnosis. Step-by-step return-to-play guidelines are established, and common misperceptions of concussion injuries are provided.

Caplan, L.J., Ivins, B., Poole, J.H., Vanderploeg, R.D., Jaffee, M.S., and Schwab, K. 2010. The structure of postconcussive symptoms in 3 US military samples. Journal of Head Trauma Rehabilitation, 25(6), 447-458.

In order to evaluate the symptoms clusters for the 22-item NSI, models utilizing 2, 3, and 9 factors were compared. Although the 9-cluster result provides a valid description for the data, the three factors model fits the data more parsimoniously.

Carroll, L.J., Cassidy, J.D., Peloso, P.M., Borg, J., von Holst, H., Holm, L., Paniak, C., and Pepin, M. 2004. Prognosis for mild traumatic brain injury: Results of the WHO collaborating centre task force on mild traumatic brain injury. Journal of Rehabilitation Medicine, 43, 84-105.

Research suggests that children consistently have quick resolution of cognitive symptoms following mTBI, and that a vast majority of adults fully recover from cognitive deficits following an mTBI within 3-12 months. Adults with symptoms that persist longer than this timeframe often have compensation or litigation factors.

Chen, J.K., Johnston, K.M., Frey, S., Petrides, M., Worsley, K., and Ptito, A. 2004. Functional abnormalities in symptomatic concussed athletes: An fMRI study. NeuroImage, 22, 68-82.

Concussed athletes performed working memory tasks concurrent to an functional magnetic resonance imaging (fMRI) scan. Symptomatic concussed athletes demonstrated activity in many but not all task-related regions, and demonstrated activation of regions not task-related. This suggests fMRI may be useful in conjunction with working memory tasks to evaluate recovery following TBI.

Chen, S.F., Richards, H.K., Smielewski, P., Johnstrom, P., Salvador, R., Pickard, J.D., and Harris, N.G. 2004. Relationship between flow-metabolism uncoupling and evolving axonal injury after experimental traumatic brain injury. Journal of Cerebral Blood Flow and Metabolism, 24(9), 1025-1036.

Rats were concussed to study direct consequences for white matter concerning local cerebral blood flow (LCBF) and glucose metabolism (LCMRglc). Measurements of LCBF and LCMRglc were taken 3 hours and 24 hours after injury. Although LCMRglc was unaffected, LCBF was significantly reduced when compared to non-concussed rats.

Chou, L., Kaufman, K.R., Walker-Rabatin, A.E., Brey, R.H., and Basford, J.R. 2004. Dynamic instability during obstacle crossing following traumatic brain injury. Gait and Posture. 20, 245-254.

Despite appearing to walk at a normal gait, individuals suffering from mTBI often complain of imbalance or unsteadiness while walking. To test gaits of those with recent mTBI, recently injured individuals were tested with a 13-link biomechanical model. mTBI individuals walked with a significantly slower gait speed and shorter stride length than matched controls, demonstrating mTBI does affect normal walking.

Collie, A., McCrory, P., and Makdissi, M. 2006. Does history of concussion affect current cognitive status? British Journal of Sports Medicine, 40, 550-551.

Athletes with a self-reported history of concussion were tested on six cognitive tasks. Results demonstrated that self-reported prior concussive events were unrelated to overall performance of the tasks.

Collins, M.W., Iverson, G.L., Lovell, M.R., McKeag, D.B., Norwig, J., and Maroon, J. 2003. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. Clinical Journal of Sport Medicine, 13, 222-229.

ImPACT (cognitive test battery) was used to test college and high school athletes following a concussive event to determine what, if any, injury characteristics such as loss of consciousness and PTA predict symptoms and neurocognitive deficits following concussion. Results suggest that PTA, but not loss of consciousness, is predictive of resulting symptoms and deficits. Thus, the researchers concluded that concussed athletes who experience PTA should be carefully monitored and assessed prior to returning to sport participation.

Covassin, T., Stearne, D., and Elbin, R. 2008. Concussion history and postconcussion neurocognitive performance and symptoms in collegiate athletes. Journal of Athletic Training, 43(2), 119-124.

Neurocognitive performance by athletes with and without a previous concussion history was evaluated using a cognitive test battery (ImPACT) 1 day and 5 days following a concussive injury. Athletes with a history of two or more concussions took longer to recover in verbal memory and reaction time domains than athletes with no prior concussions.

Cremona-Meteyard, S.L., and Geffen, G.M. 1994. Persistent visuospatial attention deficits following mild head injury in Australian Rules football players. Neuropsychologia, 32(6), 649-662.

Utilizing a visuospatial attention task, athletes recovering from a mild head injury were tested within 2 weeks of their injuries and compared to individuals with no prior injury. The mild head injury group performed similarly to the non-injured group such that their speed to respond to targets in the unexpected visual field, but were significantly slower to respond to targets in the expected visual field. This finding suggests a persistent slowed response to expected events following a mild head injury.

Dash, P.K., Zhao, J., Hergenroeder, G., and Moore, A.N. 2010. Biomarkers for the diagnosis, prognosis, and evaluation of treatment efficacy for traumatic brain injury. Neurotherapeutics, 7(1), 100-114.

TBI presents a serious health risk which can result in disability and even death. Although prevention and management have improved, a desire for a more reliable diagnosis method

exists, including secondary pathologies and predicting severity of the injury. Biomarkers are one promising potential for detecting TBI, but the data for biomarkers to detect concussions and their severity do not exist at this time.

DeHaan, A., Halterman, C., Langan, J., Drew, A.S., Osternig, L.R., Chou, L.S., and von Donkelaar, P. 2007. Cancelling planned actions following mild traumatic brain injury. Neuropsychologia, 45, 406-411.

This study observed the effect of mTBI on an individual's ability to perform a countermanding saccade task. mTBI injuries hinder attention and planning procedures, and countermanding saccade tasks require individuals to, at times, reject making saccades toward new stimuli and instead look away from them. The results indicate that mTBI individuals have a difficulty with cancelling planned actions compared to non-injured individuals.

de Kruijk, J.R., Leffers, P., Menheere, P.P., Meerhoff, S., Rutten, J., and Twijnstra, A. 2002. Prediction of post-traumatic complaints after mild traumatic brain injury: early symptoms and biochemical markers. Journal of Neurology, Neurosurgery, and Psychiatry, 73, 727-732.

Successful prediction of post-traumatic complaints (PTC) following mTBI would increase the understanding of the injury and would allow medical practitioners to predict the expected recovery of the injured. Individuals admitted into an emergency room had both symptoms and biochemical markers measured. After 6 months, mTBI individuals were again questioned concerning PTC. Researchers found that presence of increased serum biomarkers, headaches, dizziness, or nausea was strongly associated with the severity of PTC.

Devinsky, O., and D'Esposito, M. 2004. Memory and memory disorders. Neurology of cognitive and behavioral disorders. 1st ed. New York, NY: Oxford University Press, 275-301.

Book chapter addressing the different types of memory (e.g. short term, long term, declarative, procedural etc.) along with disorders and theoretical models describing processing of memory. Includes discussion of memory problems that can result from TBI, such as amnesia for the events near the time of the injury.

Drew, A.S., Langan, J., Halterman, C., Osternig, L.R., Chou, L.S., and van Donkelaar, P. 2007. Attentional disengagement dysfunction following mTBI assessed with the gap saccade task. Neuroscience Letters, 417, 61-65.

Orienting attention from one location to another requires disengaging from the current "attended to" area, movement of attention toward the desired location, and then movement of the eyes to the new location. By manipulating the time between the presentation of a cue and a stimulus, the researchers found that mTBI individuals were slower to orient to the stimuli when the gap between the cue and stimuli were relatively short. The results suggest that the disengagement process is stalled for mTBI patients for a period of 2 to 7 days following injury.

Echemendia, R.J., Putukian, M., Mackin, R.S., Julian, L., and Shoss, N. 2001. Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. Clinical Journal of Sport Medicine, 11, 23-31.

Male and female athletes who suffered an mTBI were matched with teammates and tested 2 hours, 4 hours, 1 week, and 1 month following the injury. The neuropsychological tests were more successful than self-reports in detecting cognitive impairment of the mTBI individual, with most athletes recovering within 1 week of the injury.

Faden, A.I., Demediuk, P., Panter, S.S., and Vink, R. 1989. The role of excitatory amino acids and NMDA receptors in traumatic brain injury. Science, 244(4906), 798-800.

Rats were given fluid percussion induced brain injuries. Following injury, N-methyl-D-aspartate antagonist dextrorphan was given to the rats, and demonstrated a benefit in treating acute head injury.

Field, M., Collins, M.W., Lovell, M.R., and Maroon, J. 2003. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. Journal of Pediatrics, 142(5), 546-553.

High school and college athletes who suffered concussions and matched controls underwent neuropsychological testing. High school athletes with concussions showed prolonged memory dysfunction compared to that of concussed college athletes. Concussed college athletes displayed comparable performance to matched controls in neuropsychological performance typically 3 days following injury, while high school athletes typically required 7 days following injury to perform at the same level as matched controls.

Flynn, F. G. 2010. Memory impairment after mild traumatic brain injury. Continuum Lifelong Learning Neurology, 16(6), 79-109.

Following mTBI, individuals may have anterograde and retrograde PTA during the acute phase, while working memory, attention, speed of processing, and memory acquisition issues appear to be more common during the post-acute phase following injury.

Geurts, A.C.H., Ribbers, G.M., Knoop, J.A., and van Limbeek, J. 1996. Identification of static and dynamic postural instability following traumatic brain injury. Archives of Physical Medicine and Rehabilitation, 77(7), 639-644.

Individuals with mTBIs who complained of reduced gross motor skills but demonstrated no sensorimotor impairments were compared to healthy controls. Participants were given postural tests, with mTBI patients demonstrating poorer performance especially when visual feedback was not given. Since mTBI patients were tested at least 6 months following injury, the study demonstrated long-term deficits for posture follow mTBIs.

Giza, C.C. and Hovda, D.A. 2001. The neurometabolic cascade of concussion. Journal of Athletic Training, 36(3), 228-235.

Review of over 100 articles to better determine the post-injury pathophysiology and recovery of function following concussive injuries. Initial pathophysiologic cascade leads to abrupt neuronal depolarization, release of excitatory neurotransmitters, and other alteration of the brain. The course of these injuries is best understood in animal models due to the difficulty in measuring these issues with humans. Although animals demonstrate cerebral adverse pathophysiology days following a concussion, humans may have weeks of adverse conditions.

Gronwall, D. 1989. Cumulative and persisting effects of concussion on attention and cognition. In: Levin H, Eisenberg, H., and Benton, A., eds. Mild head injury. New York, NY: Oxford University Press: 153-162.

Although most healthy adults return to baseline levels relatively soon following mTBI, some factors can increase the risks of persistent effects of injury. These factors include, but are not limited to: age, medical history, and life stressors, such that older adults, those with previous mTBI injuries, individuals who require advanced cognitive processing for their daily life and those suffering from high stressors are more likely to have persistent detriments following mTBIs.

Guskiewicz, K.M. 2001. Postural stability assessment following concussion: One piece of the puzzle. Clinical Journal of Sport Medicine, 11, 182-189.

Postural stability is very consistent for individuals that are not injured and thus practice effects are minimized for these tasks. This review discusses the applicability of postural stability assessment as an adjunct to evaluation following concussive injury.

Guskiewicz , K.M., Bruce, S.L., Cantu, R.C., Ferrara, M.S., Kelly, J.P., McCrea, M., Putukian, M., and Valovich McLeod, T.C. 2004. National Athletic Trainers Association Position statement: Management of sport-related concussion. Journal of Athletic Training, 39, 280-297.

Report concerning sport-related concussion. Concussions are given 1) a definition, 2) traits in which they can be recognized with, 3) measurements in which they can be evaluated and when a player can return to play, 4) and assessment tools in which severity can be measured. Trainers are given information on 1) when to refer athletes to physicians, 2) when to disqualify an athlete from competition, 3) concerns for the age of the athlete, and 4) home care instructions for the athlete.

Guskiewicz, K.M., McCrea, M., Marshall, S.W., Cantu, R.C., Randolph, C., Barr, W., Onate, J.A., and Kelly, J.P. 2003. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA concussion study. Journal of the American Medical Association, 290(19), 2549-2555.

In order to evaluate the cumulative effect of repeated concussive injury on recovery, college football players (with and without a history of concussions) were tested following concussive injuries. Those with three or more previous concussions showed slower average recovery times than those with one previous concussion. Additionally, players with a history of previous concussions were more likely to suffer a concussion than those with no previous concussion injuries.

Halterman, C.I., Langan, J., Drew, A., Rodriguez E., Osternig, L.R., Chou L.S., and van Donkelaar, P. 2006. Tracking the recovery of visuospatial attention deficits in mild traumatic brain injury. Brain, 129, 747-753.

Utilizing the attentional network test, this study investigated the relationship between mTBI and visuospatial attention deficits. Individuals with mTBI demonstrated deficits in orientation and executive components of the task immediately following their injury, with deficits in the later lasting around a week. These findings suggest that regions concerning both the executive components and orientation aspects of visual perception are affected by mTBI injuries.

Heitger, M.H., Anderson, T.J., and Jones, R.D. 2002. Saccade sequences as markers for cerebral dysfunction following mild closed head injury. Progress in Brain Research, 140, 433-448.

Research suggests that mTBI injuries affect the neural networks involved with planning and executing sequential memory guided saccades. Individuals with mTBI and controls were tested on 2- and 3-step sequenced memory guided saccades. Patients with mTBI, demonstrated more directional errors, larger position errors, and an overall overreaching of primary and final eye position movements.

Heitger, M.H., Anderson, T.J., Jones, R.D., Dalrymple-Alford, J.C., Frampton, C.M., and Ardagh, M.W. 2004. Eye movement and visuomotor arm movement deficits following mild closed head injury. Brain, 127, 575-590.

In order to better understand saccadic and visuomotor arm movement deficits following mTBI, a battery of tests were given to mTBI individuals and matched controls. Individuals with mTBI demonstrated deficits in the antisaccade task, higher saccadic errors, directional errors of limb movements, and poorer spatial accuracy. Smooth pursuit and random oculomotor activities were not affected by mTBI. The deficits detected suggest further ways of testing recently concussed individuals and their progression toward recovery.

Heitger, M.H., Jones, R.D., and Anderson, T.J. 2008. A new approach to predicting postconcussion syndrome after mild traumatic brain injury based upon eye movement. Engineering in Medicine and Biology Society,2008.EMBS 2008. 30th Annual International Conference of the IEEE, 30, 3570-3573.

With the knowledge that mTBI results in a deficit of eye movement tasks, researchers attempted to find if these deficits could accurately predict PCS. Participants were assessed 1 week post-injury on measures of saccades, oculomotor smooth pursuit, and upper limb visuomotor function. After 3 months, a few of the participants met the criterion for PCS. Results suggested that early eye movement function was the most effective in detecting possible PCS individuals.

Heitger, M.H., Jones, R.D., Dalrymple-Alford, J.C., Frampton, C.M., Ardagh, M.W., and Anderson, T.J. 2007. Mild head injury –a close relationship between motor function at one week post-injury and overall recovery at three and six months. Journal of the Neurological Sciences, 253, 34-47.

To better predict overall recovery of concussed athletes, researchers examined early eye and arm motor function following mTBI. Re-examination of mTBI individuals was conducted at 3 and 6 months following injury. Results suggest early assessment of eye and arm motor function can improve predicting mTBI recovery.

Hinton-Bayre, A.D., Geffen, G.M., Geffen, L.B., McFarland, K.A., and Friis, P. 1999. Concussion in contact sports: Reliable change indices of impairment and recovery. Journal of Clinical and Experimental Neuropsychology, 21(1), 70-86.

Repeated exposure to neurocognitive tasks runs a risk of demonstrating practice effects, which could mask cognitive deficits following a concussion. A reliable change index was utilized and demonstrated that most concussed athletes were impaired 1 to 3 days following injury, few were still impaired after 1 to 2 weeks, and all had returned to baseline after 3 to 5 weeks.

Hoffer, M.E., Balaban, C., Gottshall, K, Balough, B.J., Maddox, M.R., and Penta, J.R. 2010. Blast exposure: Vestibular consequences and associated characteristics. Otology and Neurotology, 31, 232-236.

Although the amount of literature concerning blunt force mTBI is extensive, the literature of blast force mTBI is relatively small and lacking. With the use of IEDs, blast force mTBI has become more common and understanding the unique qualities of the injury is required to properly treat injured individuals. Blast force mTBI is more global in the damage done to the structure of the brain, and typically results in dizziness as the primary symptom, typically requiring vestibular measures for diagnosis and rehabilitation.

Hoffer, M.E., Gottshall, K.R., Moore, R., Balough, B.J., and Wester, D. 2004. Characterizing and treating dizziness after mild head trauma. Otology Neurotology, 25(2), 135-138.

Most mTBI research is concerned with the cognitive deficits associated with the injury, while symptoms related to dizziness are rarely studied. Here, the diagnosis and treatment of balance disorders was the focus of the research. The results show that treatment should be focused on the diagnosis of balance issues rather than the severity of the injury. Although cognitive assessments are important, symptoms of dizziness following mTBI can delay an individual's return to normal life events.

Hoge, C.W., McGurk, D., Thomas, J.L., Cox, A.L., Engel, C.C., and Castro, C.A. 2008. Mild traumatic brain injury in U.S. soldiers returning from Iraq. The New England Journal of Medicine, 358(5), 453-463.

U.S. Army infantry soldiers were surveyed following their year-long deployment to Iraq. The survey was created to acquire information about injuries Soldiers had suffered. A significant amount of Soldiers reported experiencing an mTBI during deployment and suffering PTSD and/or depression along with the injury.

Hugenholtz, H., Stuss, D.T., Stethem, L.L., and Richard, M.T. 1988. How long does it take to recover from a mild concussion? Neurosurgery, 22(5), 853-858.

Concussed and non-concussed individuals were given neurological evaluations within a 3-month time frame. For those who were concussed, responses to tasks on the choice RT task were significantly slower than the comparison group. This effect was most evident during the first month after injury, with a gradual recovery over the 3-month testing period.

Huh, J.W., Widing, A.G., and Raghupathi, R., 2007. Basic science; repetitive mild non-contusive brain trauma in immature rats exacerbates traumatic axonal injury and axonal calpain activation: A preliminary report. Journal of Neurotrauma, 24, 15-27.

To further validate animal head injury models to humans, young rats were given repetitive mild non-contusive brain trauma. Although the injuries did not result in deficits of the Morris water maze, structural damage similar to those found in the injuries of human infants were found.

Hux, K., Schneider, T., and Bennett, K. 2009. Screening for traumatic brain injury. Brain Injury, 23(1), 8-14.

Individuals seeking help from four public vocational rehabilitation agencies were surveyed to determine if they had previously experienced a likely mTBI. Over 26 percent of the individuals surveyed had reported having had an mTBI, with complaints of chronic memory challenges, headaches, depression, and anxiety as the most common symptoms. The results demonstrate a high rate of individuals seeking public vocational rehabilitation agencies with mTBI history, suggesting mTBI may be a factor of the individual's current situation.

Iverson, G.L. 2005. Outcome from mild traumatic brain injury. Current Opinion in Psychiatry, 18, 301-317.

Review of the mTBI literature and the affect mTBI have on individual health and function. Although no single standard test is used following all concussion injuries, evidence suggests a majority of athletes typically return to pre-injury functioning 2 to 14 days following their injury. Some individuals do take longer to recover, and pre-existing psychiatric, substance abuse, and or poor general health may factor into the prolonged recovery of these individuals.

Iverson, G.L., Brooks, B.L., Collins, M.W., and Lovell, M.R. 2006. Tracking neuropsychological recovery following concussion in sport. Brain Injury, 20(3), 245-252.

Amateur athletes were tested with ImPACT (a cognitive test battery) three times, 1 to 2 days, 3 to 7 days, and 1 to 3 weeks following a concussion injury. Results demonstrated that a majority of the performance decrements on all five composite scores were resolved 5 days after the injury. However, 10 days after injury, 37 percent of the athletes were still below preseason performance for 2 or more of the composite scores.

Iverson G.L., Brooks, B.L., Lovell, M.R., and Collins, M.W. 2006. No cumulative effects for one or two previous concussions. British Journal Sports Medicine, 40, 72-75.

Athletes with histories of no previous concussions, one previous concussion, and two previous concussions were compared after suffering a concussion injury during season. ImPACT (cognitive test battery) test results suggest that concussion history does not play a role in cognitive deficits following a concussion injury.

Iverson, G.L., Gaetz, M., Lovell, M.R., and Collins, M.W. 2004. Relation between subjective fogginess and neuropsychological testing following concussion. Journal of International Neuropsychological Society, 10, 904-906.

High school athletes were studied to determine if a relation existed between feeling "foggy" and neuropsychological outcome (via ImPACT [cognitive test battery]) at 1 week following an mTBI injury. Athletes with persistent "fogginess" suffered from a large number of other post-concussion symptoms when compared to those who did not suffer from persistent "fogginess." Additionally, persistent "fogginess" was associated with slower reaction times, deficits in memory tasks, and slower processing speed.

Kissick, J., and Johnston, M. 2005. Return-to-play after concussion. Clinical Journal of Sport Medicine, 15(6), 426-431.

Outlines a general protocol to recognize a concussion injury and establish a return-to-play guideline. Due to the increase of knowledge on the detriments of concussion injury, proper steps must be taken, not only to return the player to the field, but to also assure that the player's health is not compromised.

Klein, E., Caspi, Y., and Gil, S. 2003. The relationship between memory of the traumatic event and PTSD: Evidence from studies of traumatic brain injury. Canadian Journal of Psychiatry, 48, 28-33.

The co-morbidity of mTBI and PTSD in Soldiers has led to research concerning what may influence this relationship. Here, a review of literature observed the relationship of memory of the injury and what role that may have in the development of PTSD. Although the theory that amnesia of the mTBI may protect against PTSD, the research is inconclusive at this time and further investigations are necessary.

Kraus, M.F., Susmaras, T., Caughlin, B.P., Walker, C.J., Sweeney, J.A., and Little, D.M. 2007. White matter integrity and cognition in chronic traumatic brain injury: A diffusion tensor imaging study. Brain, 130(10), 2508-2519.

Although it is known that mTBI often result in diffuse axonal injury, detection of axonal integrity is difficult. Researchers utilized diffusion tensor imaging to determine if it could detect white matter integrity and, if so, whether a relationship existed between white matter integrity and cognition. They found that white matter load was negatively correlated to all cognitive domains tested.

Lau, B., Lovell, M.R., Collins, M.W., and Pardini, J. 2009. Neurocognitive and symptom predictors of recovery in high school athletes. Clinical Journal of Sports Medicine, 19, 216-221.

High school athletes were given cognitive assessments after mTBI. Both neurocognitive and self-assessment results were used to determine symptom clusters to assist with predicting and classifying injuries immediately. Symptoms such as complaints of migraines, complaints of cognitive issues, poor scores on ImPACT all factor into prolonged recovery from mTBI.

Lau, B.C., Kontos, A.P., Collins, M. W., Mucha, A., and Lvell, M. R. 2012. Which on-field signs/symptoms predict protracted recovery from sport-related concussion among high school football players. The American Journal of Sports Medicine, 39 (11), 2311-2318.

To assist with predicting those who may have a slower recovery (over 21 days) and those who have a rapid recovery (7 days or less) from mTBI, researchers utilized high school athletes and measured their symptoms and length of time sidelined. The data demonstrated that reporting dizziness following a concussion was associated with a longer recovery, and no other symptoms were predictive in recovery time.

Levin, H., Gary, H., High, W., Mattis, S., Ruff, R., Eisenberg, H., Marshall, F, and Tabbador, K. 1987. Minor head injury and the postconcussional syndrome: Methodological issues in outcome studies. In H. S. Levin, J. Grafman, and H. Eisenberg (Eds.), Neurobehavioral recovery from head injury, 176-188. New York: Oxford University Press.

Although the detriments of mTBI were well documented, cases of properly matched controls and baseline data of those with mTBI were not available at this time. Effects of concussion are similar among individuals with different backgrounds, and the long term effects of mTBI are not fully understood at this time.

Ling, G., Bandak, F., Armonda, R., Grant, G., and Ecklund, J. 2009. Explosive blast neurotrauma. Journal of Neurotrauma, 26, 815-825.

With the frequent use of IEDs in warfare, it has become important to understand the differences between blunt- and blast-induced forms of mTBI. The article discusses the prevalence of blast-induced mTBI, its mechanisms, and categories. Although similar to blunt-induced mTBI, the clinical management and recovery of blast-induced mTBI may differ, as more research needs to be conducted on this danger to Soldiers.

Lipton, M.L., Gellella, E., Lo, C., Gold, T., Ardekani, B. A., Shiteh, K., Bello, J.A., and Branch, C.A. 2008. Multifocal white matter ultrastructural abnormalities in mild traumatic brain injury with cognitive disability: A voxel-wise analysis of diffusion tensor imaging. Journal of Neurotrauma, 25(11), 1335-1342.

Retrospective analysis of diffusion tensor MRI data of previously concussed patients was conducted to identify occult white matter abnormalities in patients suffering from persistent cognitive impairment. Histograms of white matter fractional anisotropy (FA) demonstrated decreased FA in patients suffering from persistent cognitive impairment, with areas such as the corpus callosum demonstrating decreased FA. High mean diffusivity (MD) was also found in these patients, suggesting that FA and MD contribute to persistent cognitive impairment.

Lovell, M.R., Iverson, G.L., Collins, M.W., McKeag, D., and Maroon, J.C. 1999. Does loss of consciousness predict neuropsychological decrements after concussion? Clinical Journal of Sport Medicine, 9, 193-198.

Hospital patients who experienced LOC following a concussion were compared to concussed individuals who did not experience LOC. The neuropsychological test measures used by the hospital, found no significant differences between the two groups, suggesting that LOC does not impact cognitive detriments following a concussion.

Macciochi, S., Barth, J., Littlefield, L., and Cantu, R.C. 2001. Multiple concussions and neuropsychological functioning in collegiate football players. Journal of Athletic Trainers, 36, 303-306.

College athletes were given neuropsychological tests and symptom checklists following a concussive event. Athletes who had suffered a prior concussion did not score significantly different from athletes without a history of concussion.

Macciochi, S.N., Barth, J.T., Alves, W., Rimel, R., and Jane, J. 1996. Neuropsychological functioning and recovery after mild head injury in collegiate athletes. Neurosurgery, 39(3), 510-514.

Athletes were tested before injury, 24 hours following injury, and 5 and 10 days following injury. When compared to non-injured gender, age, and education matched controls, concussed individuals scored worse than the matched controls at 24 hours after injury, but did not score worse at 5 or 10 days after injury tests.

Maddocks, D.L., Dicker, G.D., and Saling, M.M. 1995. The assessment of orientation following concussion in athletes. Clinical Journal of Sport Medicine, 5, 32-35.

Following concussions, athletes were giving recently acquired information to orientation questions. The authors found that scoring poorly on recently acquired information, rather than poor scores on standard orientation items, was more sensitive to a diagnosis of a concussion injury.

Makdissi, M., Collie, A., Maruff, P., Darby, D.G., Bush, A., McCrory, P., and Bennell, K. 2001. Computerized cognitive assessment of concussed Australian Rules footballers. British Journal of Sports Medicine, 35, 354-360.

Traditional paper and pencil tests were compared to computerized tests to determine comparable differences for the two measures to detect cognitive differences following a concussion. Computer tests were superior in detecting increased variability in response times, which is a potentially important deficit following concussions.

Management of Concussion/mTBI Working Group. 2009. VA/DoD Clinical Practice Guideline for Management of Concussion/Mild Traumatic Brain Injury (Summary). Retrieved 22 January 2010 from http://www.healthquality.va.gov/management_of_concussion_mtbi.asp.

Addresses the information concerning concussion injuries and guidelines the VA/DoD clinicians use to diagnosis, treat, and manage concussed individuals. Although recent knowledge gains have been obtained, the guidelines do suggest individual differences will exist and that future knowledge is necessary for a better understanding of concussed individuals.

Manville, J., Laurer, H.L., Steudel, W.I., and Mautes, A.E., 2007. Changes in cortical and subcortical energy metabolism after repetitive and single controlled cortical impact injury in the mouse. Journal of Molecular Neuroscience, 31, 95-100.

Rats were given controlled cortical impact injuries and had their regional adenosine triphosphate (ATP), glucose, and lactate content in their cortical and sub-cortical regions measured. When compared to non-injured rats, those suffering from cortical impact injuries, both cortical ATP content and lactate content decreased over time (reaching lows at 24 hours and 24 to 48 hours after injury respectively). Additionally, repetitive injuries lead to more severe depression in cerebral metabolism at early points after trauma.

Matser, J.T., Kessels, A.G.H., Jordan, B.D., Lezak, M.D., and Troost, J. 1998. Chronic traumatic brain injury in professional soccer players. Neurology, 51, 791-796.

This study was to determine the presence of chronic traumatic brain injury among professional Dutch soccer players and matched controls. All participants were interviewed and examined using an extensive neuropsychological test battery. The professional soccer players exhibited poor verbal, visual memory, planning and visuoperceptual processing tasks compared to the control subjects.

McAllister, T.W., Sparling, M.B., Flashman, L.A., Guerin, S.J., Mamourian, A.C., and Saykin, A. J. 2001. Differential working memory load effects after mild traumatic brain injury. Neuroimage, 14(5), 1004-1012.

In order to further evaluate working memory issues following mTBI, an 18-item memory self-rating scale was used for mTBI patients to subjectively rate their memory. Brain activity of the patients was measured with fMRI within 1 month of injury. Task performances do not differ significantly from controls but mTBI patients showed a different pattern of allocation of processing resources associated with the highest processing load condition to healthy controls, despite similar task performance.

McCaffery, M.A., Mihalik, J.P., Crowell, D.H., Shields, E.W., and Guskiewicz, K.M. 2007. Measurement of head impacts in collegiate football players: Clinical measures of concussion after high- and low-magnitude impacts. Neurosurgery, 61(6), 1236-1243.

The Head Impact Telemetry System, Sensory Organization Test, Automated Neuropsychological Assessment Metrics, and Graded Symptom Checklist were utilized to the effect of head impact magnitude on balance and neurocognitive performance in college football players. Balance performance and Symptomatology testing demonstrated no statically significant difference, while Neurocognitive Function showed a statistically significant increase from the baseline in the math processing and procedural reaction time.

McCrea, M., Barr, W.B., Guskiewicz, K., Randolph, C., Marshall, S.W., Cantu, R., et al. 2005. Standard regression-based methods for measuring recovery after sport-related concussion. Journal of the International Neuropsychological Society, 11(1), 58-69.

A cohort study of college football players was conducted concerning the effects of sports-related concussion from 1999 through 2001. All participants underwent a preseason baseline evaluation on a battery of concussion assessments and extensive health questionnaires prior to the first year of participation in this study. Post-concussive symptoms, cognitive functioning and balance were assessed in players with concussions and non-injured players (controls) were assessed on baseline testing. The results showed athletes with a concussion reported an increase from their baseline rate of common concussive symptoms and a significant decline from baseline cognitive performance during the acute post-injury period.

McCrea, M., Hammeke, T., Olsen, G., Leo, P., and Guskiewicz, K. 2004. Unreported concussion in high school football players: Implications for prevention. Clinical Journal of Sports Medicine, 14(1), 13-17.

High school football players were surveyed for recovery of sports related mTBI. Players reported how many prior mTBIs they had experienced. Researchers found that 30.4 percent reported a previous history of mTBIs. Findings suggest a greater frequency of concussive events in high school football players than previously estimated.

McCrea, M., Kelly, J.P., Randolph, C., Cisler, R., and Berger, L. 2002. Immediate Neurocognitive effects of concussion. Neurosurgery, 50(5), 1032-1042.

High school and college football players were tested with the Standardized Assessment of Concussion to determine if LOC or PTA played a role in cognitive deficits. Athletes with a LOC showed greater impairment immediately following injury than those with PTA and those with neither. All participants returned to baseline within 48 hours of injury.

McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Kelly, J., Lovell, M., and Schamasch, P. 2005. Summary and agreement statement of the 2nd International Conference on Concussion in Sport. British Journal of Sports Medicine, 39, 196-204.

Updates of the Vienna consensus recommendations are provided. The issue of sports concussion management is continually evolving, and the usefulness of expert consensus in establishing a standard of care has been demonstrated by the Vienna agreement.

McNamee, S., Walker, W., Cifu, D.X., and Wehman, P. H. 2009. Minimizing the effect of TBI related physical sequelae on vocational return. Journal of Rehabilitation Research and Development, 46(6): 893-908.

In this study, the common physical sequelae that affect return-to-work after TBI were evaluated. The limitations faced by many patients with TBI can best be overcome through,

clever job search, job redesign, and community linkages with business and industry that are willing to partner in helping the patients with TBI regain employment. The physician plays a key role in communicating suggestions to the vocational specialists.

Mihalik, J.P., Bell, D.R., Marshall, S.W., and Guskiewicz, K.M. 2007. Measurement of head impacts in collegiate football players: An investigation of positional and event-type differences. Neurosurgery, 61(6), 1229-1235.

To better understand concussion injuries, measurements of impact velocities and locations of hits were measured to better predict concussions of football players by position (linebacker, quarterback etc.). Data from Head Impact Telemetry System technology was used and impacts that resulted in a concussion were distinguished from those that did not. Impacts to the top of the head were more likely to result in concussions, but no other factors were significant.

Mittenberg, W., Tremont, G., Zielinski, R.E., Fichera, S., and Rayls, K.R. 1996. Cognitive-behavioral prevention of postconcussion syndrome. Archives of Clinical Neuropsychology, 11(2), 139-145.

Since no empirical evidence existed at the time for treatment concerning PSC, this study was conducted on patients admitted to a general hospital after sustaining mild head trauma. The treatment group received a printed manual and met with a therapist prior to hospital discharge to review the nature and incidence of expected symptoms, the cognitive-behavioral model of symptom maintenance and treatment, techniques for reducing symptoms and instructions for gradual resumption of premorbid activities. The control group received routine hospital treatment and discharge instructions. The treatment group experienced significantly fewer symptomatic days and lower mean severity levels.

Moser, R.S., and Schatz, P. 2002. Enduring effects of concussion in youth athletes. Archives of Clinical Neuropsychology, 17, 91-100.

The enduring effect of concussions in otherwise healthy youth athletes was studied. Half of the participating group had no history of recent concussions while the other half experienced a grade-2 or -3 concussion within 1 week prior to testing. The patients who had no recent concussions but had a history of two or more previous concussions were similar to the recently concussed group with one or none previous concussions.

Muri, R.M., and Nyffeler, T. 2008. Neurophysiology and neuroanatomy of reflexive and volitional saccades as revealed by lesion studies with neurological patients and transcranial magnetic stimulation (TMS). Brain Cognition, 68, 284-292.

Using TMS, neuro-anatomy of the cortical control of reflexive and volitional saccades of humans is studied. TMS allows specific interference of functional regions within the oculomotor network. TMS provides advantages in terms of temporal resolution, allowing interfacing with brain functioning in the order of milliseconds, hereby defining the time course of saccade planning and execution.

Niogi, S.N., Mukherjee, P., Ghajar, J., Johnson, C., Kolster, R.A., Sarkar, R., Lee, H., Meeker, M., Zimmerman, R.D., Manley, G.T., and McCandliss, B.D. 2008. Extent of microstructural white matter injury in postconcussive syndrome correlates with impaired cognitive reaction time: A 3T diffusion tensor imaging study of mild traumatic brain injury. American Journal of Neuroradiology, 29(5), 967-973.

Diffusion tensor imaging (DTI) may be a useful index of micro structural changes implicated in diffuse axonal injury linked to persistent post concussive symptoms, especially in mTBI, for which conventional MRI may lack sensitivity. Patients with recent mTBI with LOC and PTA were studied, and results showed that DTI revealed several predominant regions of damage correlating with impairments.

Paniak, C., Reynolds, S., Phillips, K., Toller-Lobe, G., Melnyk, A., and Nagy, J. 2002. Patient complaints within 1 month of mild traumatic brain injury: A controlled study. Archives of Clinical Neuropsychology, 17, 319-34.

Subjective complaints of mTBI patients were compared to controls. Patients with mTBI history had higher significant group variability in subjective complaints. However, a logistical regression model was not able to differentiate mTBI patients from non mTBI patients, even immediately following injury.

Peterson, C.L., Ferrara, M.S., Mrazik, M., Piland, S., and Elliot, R. 2003. Evaluation of neuropsychological domain scores and postural stability following cerebral concussion in sports. Clinical Journal of Sport Medicine, 13, 230-237.

Baseline performance of cognitive domain scores and posturography scores of college athletes were compared to scores following concussion injuries. Neuropsychological and balance testing were used to assess the domains of attention, concentration, learning, and short-term memory. Neurological testing provides objective measures to demonstrate recovery of concussions assisting with the prevention of a player returning-to-play too soon.

Pierrot-Deseilligny, C., Milea, D., and Muri, R.M. 2004. Eye movement control by the cerebral cortex. Current Opinions in Neurology, 17, 17-25.

Functional magnetic resonance imaging can detect posterior cingulate cortex activity associated with eye movements. These eye movements are a potential tool in detecting complex neuropsychological processes due to their real time processing of information in such tasks as spatial memory or decisional processing.

Ponsford, J. 2005. Rehabilitation interventions after mild head injury. Current Opinions in Neurology, 18(6), 692-697.

Review conducted to examine recent developments in the management and rehabilitation of individuals with mTBI to include sports-related concussions. Management seems to be very limited; and there is a need for an evidence base from which to create separate high quality guidelines for concussion management in adults and children.

Potter, S., Leigh, E., Wade, D., and Fleminger, S. 2006. The Rivermead post concussion symptoms questionnaire confirmatory factor analysis. Journal of Neurology, 253, 1603-1614.

The Rivermead Questionnaire (RPQ) was utilized to test post-concussion symptoms, around six months after admission for treatment. The results of the analysis of the RPQ administered to individuals 6 months post-concussion supports the existence of separate cognitive, emotional, and somatic factors.

Register-Mihalik, J.K., Guskiewicz, K.M., Mihalik, J.P., Schmidt, J.D., Kerr, Z.Y., and McCrea, M.A. 2012. Reliable change, sensitivity, and specificity of multidimensional concussion assessment battery: Implications for caution in clinical practice. Journal of Head Trauma Rehabilitation, doi: 10.1097/htr.0b013e3182585d37.

Concussed college athletes were compared to non-concussed athletes to provide reliable change confidence intervals for clinical measures of concussions. The sample included college-age student-athletes evaluated before and after a concussion. The outcome measures included symptom severity scores, Automated Neuropsychological Assessment Metrics throughput scores, and Sensory Organization Test composite scores. Application of the reliable change parameters suggests that a small percentage of concussed participants were impaired on each measure. The results suggest low sensitivity of the entire battery at 50 percent but high specificity at 96 percent.

Riemann, B.L., and Guskiewicz, K.M. 2000. Contribution of the peripheral somatosensory system to balance and postural. In: Lephart, S.M., and Fu, F.H., (Eds.), Proprioception and neuromuscular control in joint stability, 37-51. Champaign, IL: Human Kinetics.

Book chapter presenting the physiological foundations of the postural control system, emphasizing the somatosensory input to central processing. The significance of an individual’s somatosensory sources in postural equilibrium remains unknown, although it is apparent that all sources play a major role. Several methods of postural stability assessment are available that allow for the isolation and evaluation of various postural system components as well as different aspects of postural control.

Risdall, J.E., and Menon, D.K. 2011. Traumatic brain injury. Philosophical Transactions of the Royal Society B, 366, 241-250.

The frequency of blast-induced mTBI has increased in recent years. Intracranial pressure monitoring is not always available in clinical care settings, and protocols need to be modified to take account of this. Also, severe early oedema has led to increasing use of de-compressive craniectomy, and blast-induced mTBI may be associated with a higher incidence of vasospasm and pseudoaneurysm formation.

Savola, O., and Hillbom, M. 2003. Early predictors of post-concussion symptoms in patients with mild head injury. European Journal of Neurology, 10, 175-181.

This study, conducted in Finland, evaluated factors for predictive validity of PCS. Signs, symptoms, medical history, and lifestyle factors were recorded for 172 patients admitted to

a general, civilian hospital for mild head injury. Follow-up 1-month post-injury, allowed for PCS evaluation. The analyses (odds ratios) suggest that elevated serum protein S-100B, skull fracture, dizziness, and headache are predictors of PCS.

Servadei, F., Teasdale, G., and Merry, G. 2001. Defining acute mild head injuries in adults: A proposal based on prognostic factors, diagnosis, and management. Journal of Neurotrauma, 18(7), 657-666.

This paper addresses the issue of a lacking universal definition of mild head injury for comparison of studies in the literature. The authors suggest a reclassification of mild head injury to indicate risk level of an intracranial hematoma.

Shaw, N. A. 2002. The neurophysiology of concussion. Progress in Neurobiology, 67(4), 281-344.

Both EEG and evoked potential (EP) tests can be used to accurately study acute pathophysiology of concussions. The immediate post-concussive EEG is excitatory or epileptilform in nature, while the cortical EP waveform is lost during this period. Additionally, five theories of concussion which have been prominent during the past century are summarized and supportive evidence assessed. It is concluded that only the convulsive theory is readily compatible with neurophysiological data and can provide a totally viable explanation for concussion.

Shultz, S.R., Boa, F., Omana, V., Chiu, C., Brown, A., and Cain, D.P. 2012. Repeated mild lateral fluid percussion brain injury in the rat causes cumulative long-term behavioral impairments, neuro-inflammation, and cortical loss in an animal model of repeated concussion. Journal of Neurotrauma, 29, 281-294.

An animal model was utilized to investigate and better understand the effect of repeated concussion. Male long-Evan rats received mild lateral fluid percussion injuries or sham injuries spaced days apart. After the final injury, rats received either a short or long post-injury period, followed by detailed behavioral analysis consisting of tests for rodent anxiety-like behavior, cognition, social behavior, sensorimotor function, and depression-like behavior. Rats given mild percussion injuries displayed significant short-term cognitive impairments, along with increased anxiety and depression-like behaviors.

Sick, T.J., Perez-Pinzon, M.A., and Zhen-Zhou, F. 1998. Impaired expression of long-term potentiation in hippocampal slices 4 and 48 h following mild fluid-percussion brain injury in vivo. Brain Research, 785(2), 287-292.

This study evaluated the effects of fluid percussion brain injury on hippocampal long term potentiation (LTP) using hippocampal slices in vitro of male rats. Mild to moderate lateral fluid percussion head injury or sham operation were produced in rats prior to harvesting brain slices from the ipsilateral hippocampus. The data demonstrated that changes in functional synaptic plasticity in the hippocampus may contribute to cognitive disorders associated with TBI. Also TBI-induced effects on hippocampal LTP are robust and may be investigated in the hippocampal slice preparation in vitro.

Spain, A., Daumas, S., Lifshitz, J., Rhodes, J., Andrews, P.J., Horsburgh, K., and Fowler, J.H. 2010. Mild fluid percussion injury in mice produces evolving selective axonal pathology and cognitive deficits relevant to human brain injury. Journal of Neurotrauma, 27(8), 1429-1438.

A mouse model of mTBI was used to investigate the temporal profile of axonal and somal injury that may contribute to cognitive impairments. Male mice were used and put in two groups, mTBI and sham-operated group. The behavioral test results showed no difference in performance between the mTBI and the sham-operated group. In the extensive axonal damage, the mTBI mice showed extensive and localized axonal damage at all time points compared to sham-operated animals.

Stranjalis, G., Korfias, S., Papapetrou, C., Kouyialis, A., Boviatsis, E., Psachoulia, C., and Sakas, D.E. 2004. Elevated serum S-100B protein as a predictor of failure to short-term return to work or activities after mild head injury. Journal of Neurotrauma, 21(8), 1070-1075.

The purpose of this study was to examine the correlation of serum S-100B with short-term outcome after mTBI of patients from emergency rooms. All subjects had a Glasgow Coma Scale (GCS) of 15 with or without loss of consciousness or post-traumatic amnesia. One-third of the subjects had an elevated S-100B which correlated with an unfavorable short-term outcome.

Stuss, D.T., Stethen, L.L., Hugenholtz, H., Piction, T., Pivik, J., and Richard, M.T. 1989. Reaction time after head injury: Fatigue, divided and focused attention, and consistency of performance. Journal of Neurology, Neurosurgery, and Psychiatry, 52, 742-748.

Four specific issues concerning the effect of head injury on reaction time were observed. Different patient populations were evaluated in separate experiments and control subjects were different for each study. In conclusion, head injuries do result in deficits in attention and speed of information processing. There was no statistically significant group effect for the number of injuries.

Vos, P.E., Jacobs, B., Andriessen, T.M.J.C., Lamers, K.J.B., Borm, G.F., Beems, T., Edwards, M., Rosmalen, C.F., and Vissers, J.L.M. 2010. GFAP and S100B are biomarkers of traumatic brain injury. Neurology, 75(20), 1786-1793.

This study evaluated the predictive validity of glial fibrillary acidic protein (GFAP) and S-100B concentration in blood for TBI. Hospital patients with TBI and a GCS score of 12 were analyzed for GFAP and S-100B. For patients in unfavorable compared to favorable outcome, GFAP and S-100B was increased, confirming that GFAP and S-100B levels in serum are adjuncts to the assessment of brain damage after TBI and may enhance prognostication when combined with clinical variables.

Wall, S.E., Williams, W.H., Cartwright-Hatton, S., Kelly, T.P., Murray, J., Murray, M., Owen, A., and Turner, M. 2006. Neuropsychological dysfunction following repeat concussions in jockeys. Journal of Neurology, Neurosurgery and Psychiatry, 77, 518-520.

The purpose of this study is to determine the effects of single and repeat historical concussions on the neuropsychological functioning and neurological reports of licensed jockeys. Jockeys were assessed for neurological and neuropsychological symptoms of concussion at least three months after potential episodes. Jockeys reporting multiple historical injuries versus a single injury showed reliable decrements on a measure of response inhibition and, to a less robust degree, on divided attention.

Wilde, E.A., McCauley, S.R., Hunter, J.V., Bigler, E.D., Chu, Z., Wang, Z.J., Hanten, G.R., Troyanskaya, M., Yallampalli, R., Li, X., Chia, J., and Levin, H.S. 2008. Diffusion tensor imaging of acute mild traumatic brain injury in adolescents. Neurology, 70(12), 948-955.

This study evaluated individuals that have reported post-concussion symptoms following mTBI, despite having normal CT imaging and neurologic functioning. Adolescents with mTBI 1 to 6 days post-injury with a GCS score of 15 and a negative CT and a control group of equal age and gender uninjured had a diffusion tensor imaging tractography of the corpus callosum performed. The mTBI group demonstrated increased fractional anisotropy and decreased apparent diffusion coefficient and radial diffusivity, and more intense post-concussion symptoms and emotional distress compared to the control group.

Wilk, J.E., Herrell, R.K., Wynn, G.H., Riviere, L.A., and Hoge, C.W. 2012. Mild traumatic brain injury (concussion), posttraumatic stress disorder, and depression in U.S. soldiers involved in combat deployments: Association with post-deployment symptoms. Psychosomatic Medicine, 74, 249-257.

This study examined the associations of single and multiple deployment-related mTBIs on post-deployment health of U.S. Army Soldiers returning from Iraq or Afghanistan. Seventeen percent reported an mTBI during their previous deployment and a loss of consciousness was significantly associated with three post-concussive symptoms, including headaches. However, these symptoms were more strongly associated with PTSD and depression than with a history of mTBI. These data indicate that current screening tools for mTBI being used by the VA/DoD do not optimally distinguish persistent post-deployment symptoms attributed to mTBI from other causes such as PTSD and depression.

Wozniak, J.R., Krach, L., Ward, E., Mueller, B.A., Muetzel, R., Schnoebelen, S., Kiragu, A., and Lim, K.O. 2007. Neurocognitive and neuroimaging correlates of pediatric traumatic brain injury: A diffusion tensor imaging (DTI) study. Archives in Clinical Neuropsychology, 22(5), 555-568.

The sensitivity of diffusion tensor imaging to micro-structural white matter damage in mild and moderate pediatric TBI was tested with children with and without TBI. Children with TBI showed slower processing speed, working memory and executive deficits, and greater behavioral dysregulation when compared to children with no injury. The TBI group had

lower fraction anisotropy (FA) in three white matter regions: inferior frontal, superior frontal, and supracallosal.

Wrightson, P., and Gronwall, D. 1981. Time off work and symptoms after minor head injury. Injury, 12, 445-454.

A study observing time off work for men following mTBI demonstrated a mean time off from work of 4.7 days. Factors contributing to longer periods of time off were: older patients, traffic crashes, and alcohol use. Ninety days after the incident, 20 percent still had symptoms, mostly deficits in memory, concentration and work capacity.

Zink, B.J., Szmydynger-Chodobska, J., Chodobski, A. 2010. Emerging concepts in the pathophysiology of traumatic brain injury. Psychiatric Clinics of North America, 33(4), 741-756.

Mild TBI, which was previously not well-characterized or understood when compared to TBI, received a great deal of attention in neuroscience and the media in recent years. At the other end of the spectrum, the consequences of blast injuries from explosive devices in military personnel serving in Iraq and Afghanistan have been a grim reminder that severe TBI is responsible for most of the deaths and long-term disability in people who suffer traumatic injuries.

Zhang, L., Yang, K.H., and King, A.I. 2004. A proposed injury threshold for mild traumatic brain injury. Journal of Biomechanical Engineering, 126(2), 226-236.

An attempt is made to delineate actual injury causation and establish a meaningful injury criterion through the use of the actual field accident data for head to head collisions in professional football games. These injuries were duplicated using a validated finite element human head model. The injury predictors and injury levels were analyzed based on resulting brain tissue responses and were correlated with the site and occurrence of mTBI. There is evidence that sudden changes of intracranial pressure, shear stress concentration, and relative motion between the brain and skull do indeed cause surface contusion, concussion, diffuse axonal injury, as well as acute subdural hematoma.

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